An effective antioxidized strategy for Ag based film-dielectric-metal plasmonic sensor

YulianLi, Jun Gao, Xuejia Lu

Abstract—An effective strategy to avoid the Ag antioxidized problem of the ultra-narrow dualband plasmonic sensors was proposed and demonstrated theoretically by introducing a thin MgF_2 layer above the upmost Ag grating surface. The two peaks have different response to the refractive index of the surrounding medium. The resonant wavelength of the sensor is easily tunable via geometrical scaling of the sensor structure and thickness of the MgF_2 layer. The sensor is ultrasensitive to the refractive index of the environmental dielectric with the sensitivity as high as 450nm/RIU. This dualband antioxidized plasmonic metamaterial optical absorber has great potential to improve the performance of sensors in practical applications.

Index Terms—Surface plasmon, dualband plasmonic sensor, antioxidized layer, Ag based film-dielectric-metal structure.

I. Introduction

PLASMONIC have been rapidly developed in recent years due to their near-unity absorption ability and controllable absorption properties. Thus they are intensively used in a wide variety of area, such as energy harvesting, plasmonic sensor, photon detectors, absorption filters, thermal emitters and nonlinear optics. Especially, in the visible and near-infrared realm, plasmonic absorbers play an important role in detecting small quantities preferably down to single molecules. For detecting the concentration of molecule, the nearly perfect absorption sensors based on plasmonic absorbers should be very sensitive to the refractive index of the surrounding medium.

Recent studies indicate the sensitivity of plasmonic sensors can be improved markedly by narrowing their band range or full-width at half maximum (FWHM). Nanostructured metals and metal-dielectric-metal (MIM) metamaterials have been used to realize narrowband plasmonic sensors with near-perfect absorption in the visible and near-infrared realm. But, the resonant absorption bandwidth of the absorbers is relatively broad due to inherent large optical losses in metals that decrease the quality factor of optical resonators. Latest advances on the nearly perfect plasmonic absorbers show that Ag has a good performance using for the ultra-narrow band absorbers. However, the oxidized problem of the Ag material still limits the stability and working life of the Ag-based plasmon sensors which puts a limit on the practice application of the Ag-based plasmon sensors. Recent develops on the thin film deposition show powerful ability on the antioxidized problem.

In this work, we propose and theoretically demonstrate an effective strategy to avoid the Ag oxidized problem of the dualband plasmonic absorbers by introducing a thin MgF_2 layer above the upmost Ag grating surface, which doesn't influence the high sensitivity of the plasmonic absorbers. The resonant wavelength is easily tunable via geometrical scaling of sensor and thickness of MgF_2 layer. The plasmonic absorbers are ultrasensitive to the refractive index of the environmental dielectric with its sensitivity as high as 450nm/RIU and FOM as high as 100. Importing such thin MgF_2 layer on Ag grating surface is a promising route for avoiding oxidation problem and achieving ultranarrow multiband band high sensitivity absorbers, which can immensely promotes the practical application of sensors based on plasmonic absorbers.

II. Numerical investigation

The plasmon absorber is based on Ag based metal film-dielectric-metal (MIM) structure. In order to avoid the Ag oxidized problem, we introduce a thin MgF_2 layer above the upmost Ag surface with its depth and width as d as illustrated in Fig.1(a). Fig.1(a) presents the schematic diagram's cross section of a unit cell of the plasmon absorber. The grey region is silver, the green region is Al_2O_3, and the blue region is MgF_2. The depth and width of the thin MgF_2 layer is denoted as d. The thickness and the width of the grating ridges are denoted as t and w. The thickness of the Al_2O_3 is denoted as b. The thickness of the Ag film is denoted by h and the lattice constant is assumed to be a. A plane wave light source is used for illumination with its propagation direction and polarization along the negative z-axis and x-axis, respectively.

The spectral characteristics of the plasmon absorbers are calculated by performing electromagnetic wave finite difference time domain method (FDTD, available from Lumerical software package [1]). The permittivity of Ag is extracted from Johnson and Christy's work [2] in 1972 and simulated by Drude mode [3]. The refractive index of Al_2O_3 is 1.75, and the refractive index of MgF_2 is 1.38. All materials are assumed to be nonmagnetic (i.e., $\mu = \mu_0$). The absorption spectrum (A) of the device is retrieved from scattering parameters as follows: $A = 1 - T - R$, where A, R and T denotes the

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absorption, reflection and transmission, respectively. In this work, the optically thick (100 nm) bottom silver film prevents the light transmission ($T = 0$) and therefore the absorbance is $A = 1\text{-}R$.

As depicted in Fig. 1(b), there are two peaks with the maximum absorption over 99%, denoted as Peak 1 and Peak 2, arranged from the high frequency to low frequency. The resonant wavelength of the sensor is easily tunable via geometrical scaling of the sensor structure and thickness of the MgF_2 layer. The optimal performance of the sensor occurs at the parameters as follows: d=2 nm, w = 50 nm, t = 30 nm, b =9 nm, h = 100 nm, and a = 500 nm. The bandwidth, the full width at half maximum (FWHM), of the reflection dip about 518 nm is about 4 nm, and the FWHM of the reflection dip about 682 nm is about 26 nm. The different FWHMs of the two peaks lead to different characteristics to outer environment.

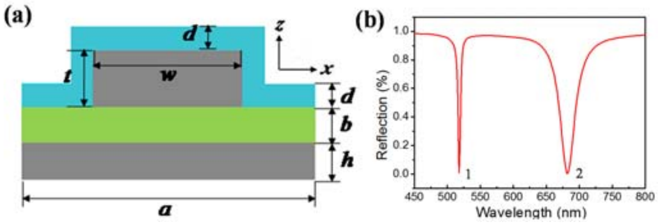

Fig.1. (a) The cross section of a unit cell of the plasmon absorber. The grey region is silver, the green region is Al_2O_3, and the blue region is MgF_2. The depth and width of the thin MgF_2 layer is denoted as d. The thickness and the width of the grating ridges are denoted as t and w. The thickness of the Al_2O_3 is denoted as b. The thickness of the Ag film is denoted by h and the lattice constant is assumed to be a. A plane wave light source is used for illumination with its propagation direction and polarization along the negative z-axis and x-axis, respectively. (b) The reflection spectrum of the plasmonic absorber with the parameters setting as follows: d =2 nm, w = 50 nm, t = 30 nm, b=9 nm, h = 100 nm, and a = 500 nm.

For nanometallic structure, resonant wavelength depends on the refractive index of the environmental dielectric, which is utilized to evaluate the performance of different types of plasmonic absorbers. The full-width at half-maximum (FWHM) is another factor determining the performance of plasmonic sensors. Thus an overall performance parameter of the plasmonic sensor is defined as sensitivity ($S = d\lambda/dn$) and figure of merit (FOM), FOM = $d\lambda/dn$/FWHM, introduced by J. Becker [4], where $d\lambda$ is resonant wavelength shift, dn is the refractive index change and FWHM is the full width of the half maximum at the absorption peak. Under normal incidence, the dependence of absorption spectra on the refractive index of the environmental dielectric n is shown in Fig. 2(a) with the structure parameters set as follows: d =2 nm, w = 50 nm, t = 30 nm, b=9 nm, h = 100 nm, and a = 500 nm. As n varies, the two absorption peaks intensity remain near unity, but the absorption peaks wavelength redshift almost linearly. So according to the definition of S, the sensitivity of the Peak 1 remain unchanged, which is about 450 nm/RIU, shown in Fig.2(b) in the blue star. And the sensitivity of the Peak 2 is almost unchanged too, which is about 140 nm/RIU, shown in Fig.2(b) in the navy triangle. The FOM of Peak 1 declines from 100 nm to 70 nm due to the larger FWHM, shown in Fig.2(b) in the green rectangle. And the FOM of the Peak 2 is about 5 and almost unchanged, shown in Fig.2(b) in the red circle. The two peaks have different response to the refractive index of the surrounding medium, which may have a positive performance for the sensor application due to the difference sensor sensitivity response. The characterized wavelength in our work mainly focuses on the visible region which is compatible to the current data of the plasmonic sensor [5, 6], only being less than some of them [7]. Thus, the plasmon absorber has an excellent performance for detecting the refractive index fluctuation of the surrounding environment after introducing the MgF_2 layer.

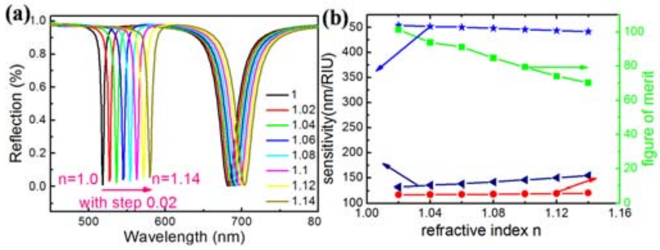

Fig.2. (a) The reflection spectra as the functions of the refractive index of the environmental dielectric varying from 1 to 1.14; (b) The sensitivity and FOM (FOM=Max|$d\lambda/dn$/FWHM|) of the plasmon absorber as the functions of the refractive index of the environmental dielectric. The sensitivity and FOM of Peak 1 are shown in the blue star and green rectangle respectively, and the sensitivity and FOM of Peak 2 are shown in the navy rectangle and red circle respectively.

III. Conclusion

In summary, we proposed an effective strategy to avoid oxidized problem of the Ag based film-dielectric-metal plasmonic sensor by introducing a thin MgF_2 layer above the upmost Ag surface, which does not affect the performance of the plasmoinc sensors. The two peaks have different response to the refractive index of the surrounding medium, which may have a positive performance for the sensor application due to the difference sensor sensitivity response. The expected perfect absorption (100% absorbance), narrow FWHM of 4 nm, high sensitivity about 450 nm/RIU, and high FOM about 100 are achieved. This wok may greatly promote the practical application of sensors based on plasmonic absorbers.

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